THE HALL AND CORBINO EFFECTS.

By E. P. ADAMS.

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About four years ago Professor Corbino[1] described some effects which are closely related to the Hall effect. These new effects all have to do with the production of a secondary circular current in a metallic disk when a primary radial current is sent through it, and the disk placed in a magnetic field perpendicular to its plane. The only metal in which Corbino was able to detect any of these effects was bismuth, perhaps owing to lack of sensitiveness in his methods, but more probably because he seems to have neglected to take the precaution of preventing circular currents in a parallel disk used to lead the radial current into the disk under investigation. These circular currents would produce an effect which would largely balance the effect sought.

Last year Mr. Chapman and I[2] measured this Corbino effect in twelve different metals. In two other metals, tin and zinc, the effect was too small to measure. The method of measurement consisted in measuring the current induced in a coil of wire placed parallel to the disk when the radial current was reversed about twenty times a second by a rotating commutator.

The result of these measurements showed that the circular current C, produced, was proportional to the magnetic field, H, and to the radial current, I, or

$$C = aHI.$$

In the magnetic metals and in bismuth a is not constant but it depends on the magnetic force. In all the other metals tried a appears to be constant.

In order to compare this effect with the Hall effect, we may

[1] *Physikalische Zeitschrift*, XII., pp. 561, 842, 1911.
[2] *Philosophical Magazine*, XXVIII., p. 692, 1914.

assume that the effect of the magnetic field is to produce an electric intensity at right angles to both the magnetic force and to the primary electric intensity, and proportional to their product and the sine of the angle between them. This we may take to be:

$$E' = cVHE,$$

where V stands for the vector product. Applying this to the Corbino effect in a circular disk where r_2 is the external radius and r_1 the internal radius we find:

$$E = \frac{I}{2\pi ktr},$$

where I is the whole radial current, k, the specific conductivity, and t the thickness. Then the transverse electric intensity is

$$E' = \frac{cIH}{2\pi ktr}$$

and the whole circular current:

$$C = \frac{c}{2\pi} \log \frac{r_2}{r_1} \cdot IH.$$

Therefore the constant a is equal to $(c/2\pi) \log (r_2/r_1)$

$$c = \frac{C}{IH} \frac{2\pi}{\log \frac{r_2}{r_1}}.$$

We may now make the same hypothesis about the Hall effect. Here it is known that if a current I flows through a rectangular sheet metal of length l, breadth b, and thickness t, there is a transverse difference of potential given by

$$e = R\frac{HI}{t},$$

R being the Hall constant. The transverse electric intensity is now

$$E' = \frac{cHI}{kbt},$$

and thus the transverse difference of potential is

$$e = \frac{c}{k}\frac{HI}{t}.$$

Thus

$$R = \frac{c}{k}.$$

The constant c may be determined from both the Hall and Corbino effects. Experiments that Mr. Chapman has recently been making show that c is the same when measured by the two effects.

Now it is known that the Hall effect varies in sign from metal to metal. This change in sign may be introduced in the hypothesis by supposing that the constant c varies in sign for different metals. The experiments that have been made show that the Corbino effect changes in sign with the Hall effect. Thus there can be little doubt that these two effects are essentially the same, and that any explanation of one effect will explain the other.

Corbino also showed that when a disk carrying a radial current was placed in a magnetic field so that the normal to the disk made an acute angle with the direction of the field, a torque was brought into play tending to make the disk parallel to the field. If ϕ is the angle between the normal to the disk and the magnetic force, the mutual energy of the circular current and the magnetic field is

$$W = \frac{c}{8\pi} \cdot IH^2S \cos^2 \phi,$$

where S is the area of the disk. Thus the torque tending to increase ϕ is

$$-\frac{\partial W}{\partial \phi} = \frac{c}{8\pi} IH^2S \sin 2\phi.$$

Mr. Smith has succeeded in measuring this torque in four or five different metals, including bismuth, and the values of c calculated from his results are in good agreement with those obtained from the measurement of the circular current.

The production of a circular current in a disk by a magnetic field acting on a radial current implies an increase in its resistance.

This increase may be readily calculated. The rate of heat production by the radial current is

$$\frac{I^2 \log \frac{r_2}{r_1}}{2\pi kt}.$$

By the circular current it is

$$\frac{2\pi C^2}{kt \log \frac{r_2}{r_1}} = \frac{c^2 I^2 H^2 \log \frac{r_2}{r_1}}{2\pi kt};$$

the total rate of heat production is thus

$$\frac{I^2 \log \frac{r_2}{r_1}}{2\pi kt}(1 + c^2 H^2).$$

If k' is the conductivity of the disk in the magnetic field we may write the total rate of heat production when a radial current I is sent through it

$$\frac{I^2 \log \frac{r_2}{r_1}}{2\pi k' t}.$$

Thus

$$\frac{k}{k'} = \frac{\sigma'}{\sigma} = 1 + c^2 H^2 \quad \text{or} \quad \frac{\partial \sigma}{\sigma} = c^2 H^2.$$

In this expression σ is the specific resistance of the metal and σ' its effective specific resistance in the transverse magnetic field. Now according to this view the resistance of a conductor should always be increased by a magnetic field. It is known, however, that with some metals notably iron and nickel, the resistance is decreased in a transverse magnetic field. Furthermore, the increase of resistance calculated from this formula is very much less than the increase actually observed. In the thought that the change of resistance might be dependent on the geometrical form of the metal Mr. Lester has measured the effect of a transverse magnetic field on the resistance of a number of metals, using disks with a radial current.

His results are in good agreement with previous measurements made with wires and strips. For example, in the case of bismuth, using the same disk that was employed to measure the circular current he found, for a field $H = 5{,}000$, $\delta\sigma/\sigma = 0.16$. Now $c = 2 10^{-5}$ for $H = 5{,}000$, so that $c^2H^4 = .01$. It is thus certain that some other influence is effective in causing the main part of the change of resistance of a metal in a magnetic field; it is very probable that the field affects the molecular structure of the metal.

The interpretation of these results from the point of view of the electron theory of metallic conduction is unsatisfactory. I have worked out their theory[3] assuming free electrons in the metal that collide with the metallic atoms and obtained very simple expressions for the number of electrons in unit volume and their time between collisions. The numbers so obtained are of the same order of magnitude as have been obtained by other methods. But the difficulty of accounting for the difference in sign of the effect for different metals on any such simple theory indicates that if we are to hold to the electron theory of metallic conduction other forces than those resulting from collisions like those between hard elastic spheres must be supposed to act upon the electrons. The surprising thing is that so much can be explained by the simple theory of electrons when all such forces are neglected.

We have seen that the Corbino effect is, essentially, the same as the Hall effect. In its measurement and interpretation the Corbino effect has some important advantages over the Hall effect. In the first place it is not necessary to use the very thin films that are required to produce measurable Hall effects. And in the second place the absence of the free transverse boundaries render the interpretation of the Corbino effect simpler than that of the Hall effect.

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[3] *Philosophical Magazine*, XXVII., p. 244, 1914.